COMPARATIVE STUDY BETWEEN ACTIVE AND HYBRID POWER FILTERS FOR POWER QUALITY ENHANCEMENT

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COMPARATIVE STUDY BETWEEN ACTIVE AND HYBRID POWER FILTERS FOR POWER QUALITY ENHANCEMENT

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

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CERTIFICATE

This is to certify that the thesis entitled "**Comparative study between active and hybrid power filters for power quality enhancement**", submitted by **Debasish Mahapatra (Roll. No. 109EE0060) and Rakesh Kumar Sahu (Roll. No. 109EE0060)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work has not been submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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ABSTRACT

In this thesis a comparative study between a single-phase shunt active power filter, single phase shunt hybrid power filter and a three phase filter with series connection of passive and hybrid filter has been cited. Due to tremendous achievements on efficiency and regulation of power electronics devices their use has been increased. But in the same way they have become the sole cause of harmonic distortion affecting power quality of the system.

Indirect control scheme having unipolar pulse width modulation (U-PWM) has been used in both single phase shunt active power filter (SPSAPF) and single phase shunt hybrid power filter (SPSHPF). The additional component used in a SPSHPF is a power factor correction capacitor (PFC) that is connected in series with a transformer. The voltage source inverter which is the main component of the filter, is connected with the primary winding of transformer. In indirect current control scheme extraction of reference source current is achieved from the distorted load current. The U-PWM technique is used for generating gate signals by comparing a high frequency triangular wave (carrier signal) with a low frequency regulation signal and it’s opposite.

A combined environment of series attachment of a passive filter and a small rated active filter can have better compensation performance which has been used for a three phase supply. While the passive filter mitigates load produced harmonics the active filter helps to enhance filtering properties of passive filter. This ensures a great diminution of the rating of the active filter guiding to an economical practical system.

The simulation of a typical distribution was carried out to validate the proposed filter techniques. It has been found that SPSHPF has a much better performance than SPSAPF. Also the series connected passive and active filter has effective harmonic mitigation quality.

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CHAPTER 1

Introduction

The rising interest in the use of electronic devices levies nonlinear loads to the source that draw active current, reactive current and harmonic current. Due to the reactive current and harmonic current electromagnetic interference with nearby equipment and heating of transformers occur. Power system can sop up harmonic currents with no problem. Resonant condition mainly affects the power problem.

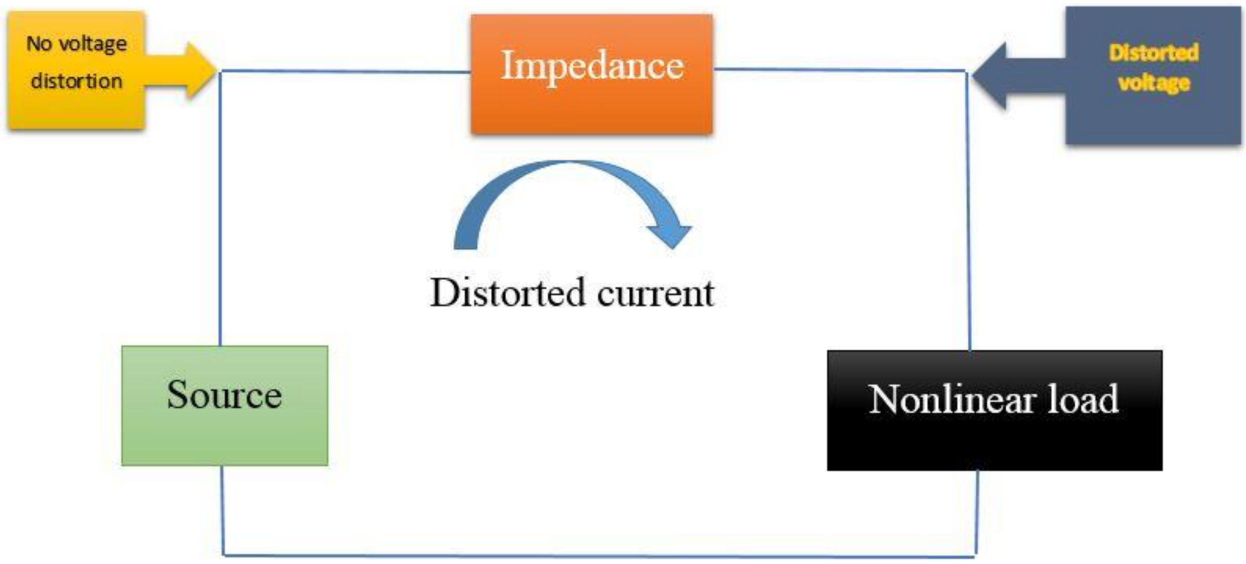

Fig.1.1. Flow of harmonic currents and generation of harmonic voltages.

In fig.1.1 the source refers to the three phase source (generator) in power system and impedance represents the line impedance. Due to the nonlinear load the current becomes non sinusoidal. As a result we are getting a distorted voltage across the load.

Most of the schemes used for harmonic reduction try for bringing the current waveform to sinusoid. The drawbacks are

i. As the current sharper is in series with the main path it demands higher rating semiconductor devices.

ii. When a prevailing sharper needs to be replaced the process becomes uneconomical as it requires significant change. [1],[3]

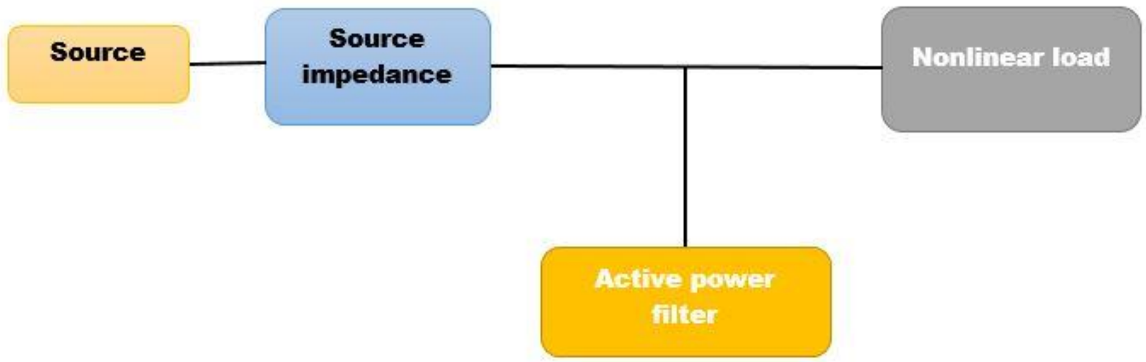

Fig.1.2. Schematics of a system with the shunt active power filter.

Fig. 1.2 shows an active power filter connected in parallel with the main path invalidates all the harmonic current and reactive current from nonlinear loads. As the active power filter provide a fraction of total power for compensation of harmonic and reactive currents it can have low rating which is economical. Among the various control strategies of active power filters pulse width modulation scheme is an efficient one. A hybrid power filter which is a combination of passive filter and active filter improves the resonance characteristics and reduces filter rating.

CHAPTER 2

Harmonics

2.1. Introduction:

Harmonics are deformation in the conventional electrical current wave shape. These are integral multiples of the central power frequency. For the analysis of complex signals Fourier Transform is used. This can be Fast Fourier Transform or Discrete Fourier Transform. These methods give results only when the signal contains only the fundamental and harmonic frequencies in a definite frequency range (known as Nyquist frequency, i.e. half of the sampling frequency). Alteration in the values of frequency components during measurement duration leads to misinformation. If the central frequency is 50 Hz, then the 2^{nd} harmonic is 100 Hz, 3^{rd} harmonic is 150 Hz and so on. The FFT can't distinguish the 140 Hz directly. The 50 Hz, 100 Hz, 150 Hz, … , are called "bins". The harmonics which are not integer multiples of fundamental harmonic are called "inter harmonics". Inter harmonics which have frequency less compared to the fundamental frequency are known as sub harmonics. Stiffness of the power distribution system and the susceptibility of an equipment are the measures how the presence of harmonics affects the running of different equipment. For the case of a stiff system due to low system impedance the value of fault current becomes high where the low aberration in voltage doesn't pose any serious problem. But for a weak system large voltage distortion as a result of large system impedance creates problem. [6]

Some definite types of equipment non immune to harmonic distortion are:

- The odd triplet harmonics in three phase wye circuits sum up with the neutral. This happens due to the fact that harmonic number multiplied by 120 degree phase shift between each phase results in an integral multiple of 360 degree causing harmonics from each phases to become in phase in the neutral.
- Incorrect reading in including induction disc, watt hour meters and averaging type current meters.

- Due to different harmonics having different sequencing values in balanced systems there is possibility of forward torque, backward torque and no torque in case of motors, generators.
- Failure of electronic equipment.
- Protective devices comprising zero crossing sensing circuits can experience false tripping of relay and failure of a UPS to transfer the right way.
- Voltage sub harmonics in the range of 1-30 Hz causes flickering of lights especially at 8.8 Hz where the human eye is most sensitive.
- Due to un-insulated bearings of electric motors shaft currents can do bearing failure.

2.2. TYPES OF LOADS:

2.2.1. LINEAR LOADS:

A linear load is defined as a load that offers unvarying impedance to the supply voltage leaving the current wave shape to change directly in proportion to the supply voltage. If the supply voltage waveform is sinusoidal a constant impedance ensues a sinusoidal current waveform. Some representation of linear loads are resistance heating, incandescent lighting, motors etc.

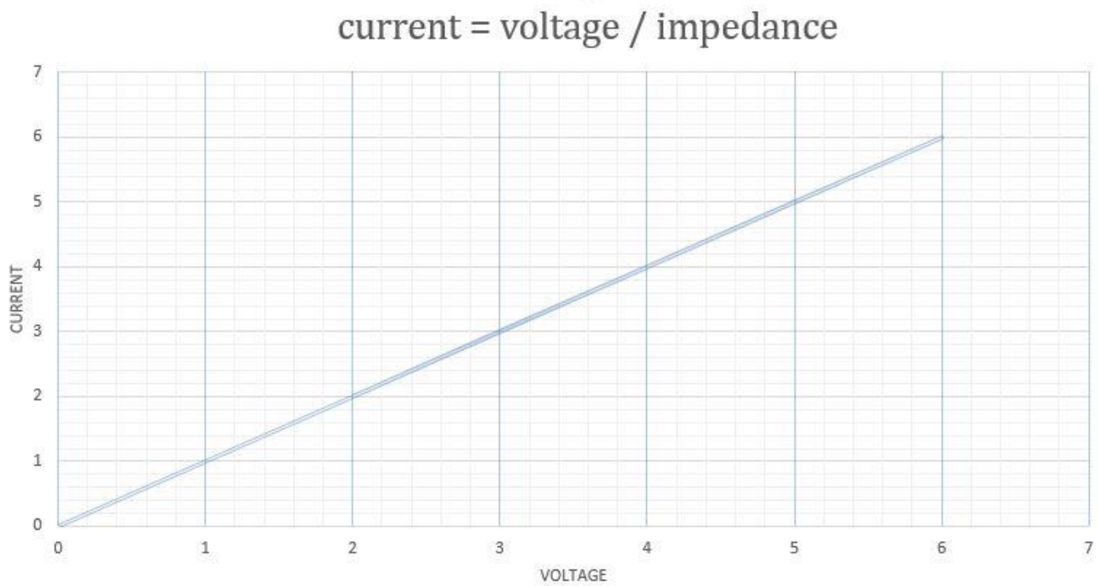

Fig.2.1. Current vs. voltage relationship in a linear load.

Fig.2.1 shows that current varies in direct proportion with respect to the voltage in case of a linear load. This is a straight line having the slope equal to impedance of the load.

2.2.2. NONLINEAR LOADS:

A nonlinear load offers varying impedance to the applied voltage so that the current waveform doesn't vary according to the voltage waveform. This leads to a non-sinusoidal current waveform. Nonlinear loads provide large impedance at some part of voltage waveform. The impedance is sharply brought down as the voltage achieves the region of peak value. For the low impedance offered by load the current rises sharply and again with sudden rise in the impedance value the current experiences a sudden drop. As the voltage and the current waveform are no more colligated they are stated as "nonlinear". Some illustrations of nonlinear loads are laser prints, uninterruptible power supply, drives with altering speeds, loads with diode-capacitor power supplies etc. These loads attract short pulse currents at time of crest of the line voltage. These non-sinusoidal current pulses insert unforeseen reflective currents back to the power distribution system resulting in functioning of current at frequencies apart from primal frequency i.e. 50 Hz. [2]

2.3. HARMONIC PRODUCING LOADS:

- The phase controlled rectifiers and inverters are the master seed of harmonics known as static power converters. These devices have firing angle control strategy that decides the conduction period of valves. A distinctive example is SMPS used in most computers. The rectifier comprises of diodes having only one direction of conduction needs voltage difference between two ends of diode. A capacitor is being fed during the rectification mode. When input voltage is more than the voltage across the capacitor diodes conduct in forward direction and the resulting load current becomes non-sinusoidal.
- Ballasts used in Fluorescent tubes are nonlinear inductors. The 3^{rd} harmonics are prevailing in this case as 3^{rd} harmonic current in individual phase adds up to neutral instead of cancelling out.
- AC voltage governors (low power) used for light dimmers and small induction motors correct phase angle. Metal diminution operation and HVDC utilize large power converters. In 3-phase equipment's irregular turn-off of semiconductor devices under naturally commutation environments can raise power quality problems. This is also a common problem experienced in forced commutated conditions.
- During energizing of a transformer first time inpouring of magnetizing current introduces harmonics. This is enriched by 2^{nd} harmonics mainly and some other harmonics. Hence an unbalanced transformer with different input voltages in each leg gives rise to harmonics. [7]

Almost all electrical loads give rise to symmetrical current waveform i.e. positive and negative half of the waveform are mirror images of each other. The outcome is only the odd harmonics and even harmonics are absent. Unsymmetrical current waveform consists of both odd and even harmonic. Arc furnaces are generator of even harmonics. Hence our system is mainly comprised of odd harmonics.

2.4. HARMONIC INDEX:

- ✓ Form factor of a wave can be used for detection of harmonics.

$$Form\ factor = \frac{rms\ value}{average\ value} \tag{2.1}$$

The ratio of root mean square (RMS) value and average value for an alternate current waveform is called ‘form factor’. Form factor for a sine wave is 1.11 approximately. If after examination of a certain sinusoidal waveform the form factor differs from 1.11 then it is contaminated with harmonics.

- ✓ Crest factor of a wave can be used for detection of harmonics.

The ratio of peak value to the root mean square (RMS) value for a waveform is known as ‘crest factor’. A typical sinusoidal wave has a value of crest factor as 1.414. Crest factors other than 1.414 indicate a deformation in the waveform. Typically deformed current waveforms show crest factor greater than 1.414 and distorted voltage waveforms have crest factor lower than 1.414. Distorted waveforms with crest factor lower than 1.414 lower than 1.414 is known as “Flat Top” voltage waveforms. [4]

- ✓ Due to fluctuations in loads distribution system can undergo frequency deviation. The change in frequency can be determined as deviation of instantaneous frequency from the nominal frequency.

$$\Delta f = f - f_N \tag{2.2}$$

f is the instantaneous frequency value and f_N is the nominal frequency.

The relative frequency deviation is defined as

$$RFV = \frac{\Delta f}{f_N} = \frac{f - f_N}{f_N} \tag{2.3}$$

- ✓ The total harmonic distortion of voltage is defined as

$$VTHD = \frac{\sqrt{\sum_{h=2} V_h^2}}{V_1} \tag{2.4}$$

The total harmonic distortion of current is defined as

$$ITHD = \frac{\sqrt{\sum_{h=2} I_h^2}}{I_1} \tag{2.5}$$

Here V and I represent rms values. 1 and h represent fundamental and the harmonic order respectively.

CHAPTER 3

Filters

3.1. TYPES OF FILTERS:

The power system must be free from harmonics and which will lead to numbers of benefits. A clean network has less strain on appliances and their lifespans are lengthened. Maintenance and replacement costs are lowered. So we go for filters. Filters can be classified into three types:

1. Passive filter
2. Active filter
3. Hybrid filter

3.1.1. PASSIVE FILTERS:

Passive harmonic filters consisting of capacitors, inductors, and resistors can be classified into

(i) Tuned filters

(ii) High pass filters.

Tuned filters:

Tuned filters are used to filter out particular harmonic frequency.

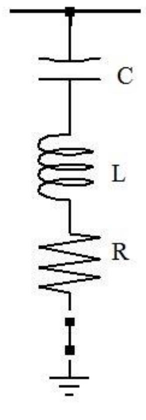

Fig.3.1. A single tuned filter.

Fig. 3.1 shows a Single tuned filter having series connection of a capacitor, an inductor, a resistor and separate out a single frequency harmonic. [5]

A double tuned filter has characteristics of providing low impedance path to 2 harmonic frequencies. It has advantage of low loss at the lower frequencies. A double tuned filter is shown in fig.3.2.

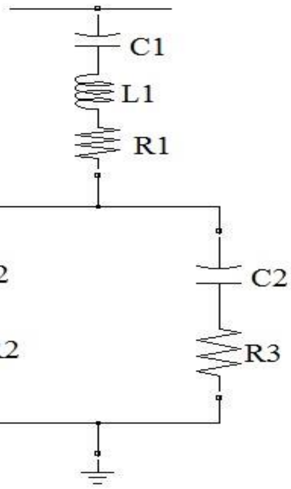

Fig.3.2. Double tuned filter.

High pass filter:

The characteristic of high pass filters is to offer low impedance path to all the high frequencies.

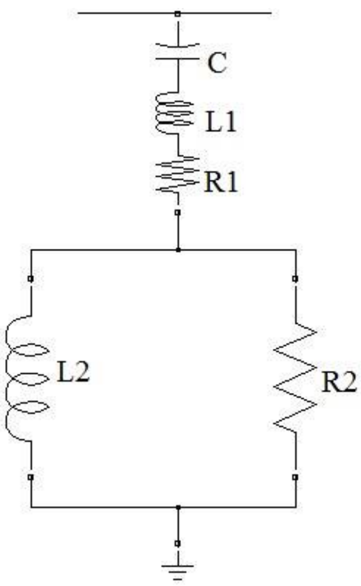

Fig.3.3. High pass filter.

Fig. 3.4 shows a C-type high pass filter having a capacitor in series with the inductor L_2 which provides low impedance path to low frequencies. This helps in reducing the loss at low frequencies.

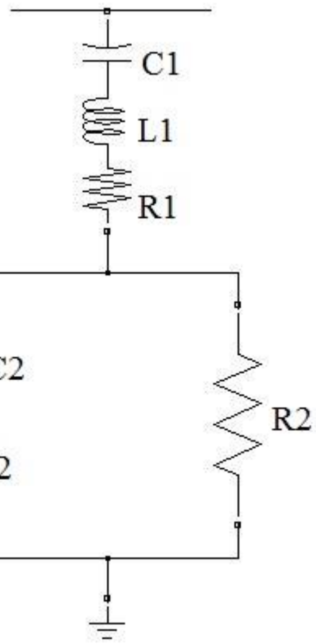

Fig.3.4. C-type high pass filter.

Passive filters are connected in parallel with nonlinear loads such as diode/thyristor rectifiers, ac electric arc furnaces, and so on. Among them, the combination of four single-tuned filters to the fifth, seventh, 11th and 13th-harmonic frequencies and a second-order high-pass filter tuned around the 17th-harmonic frequency has been used in a high-power three-phase thyristor rectifier. The drawback of passive filters is that they create resonance condition at particular frequencies they are intended to work for. This raises the magnitude of harmonic voltages at that particular frequency.[8]

3.1.2. ACTIVE FILTERS:

Pure active filters can be classified into two types according to their circuit configuration-

I. Shunt (parallel) active filters

II. Series active filters

Shunt active filters have more advantage over series active filters regarding their form and function. So series active filters are basically suitable only for harmonic filtering.

Shunt active filter circuit configuration:-

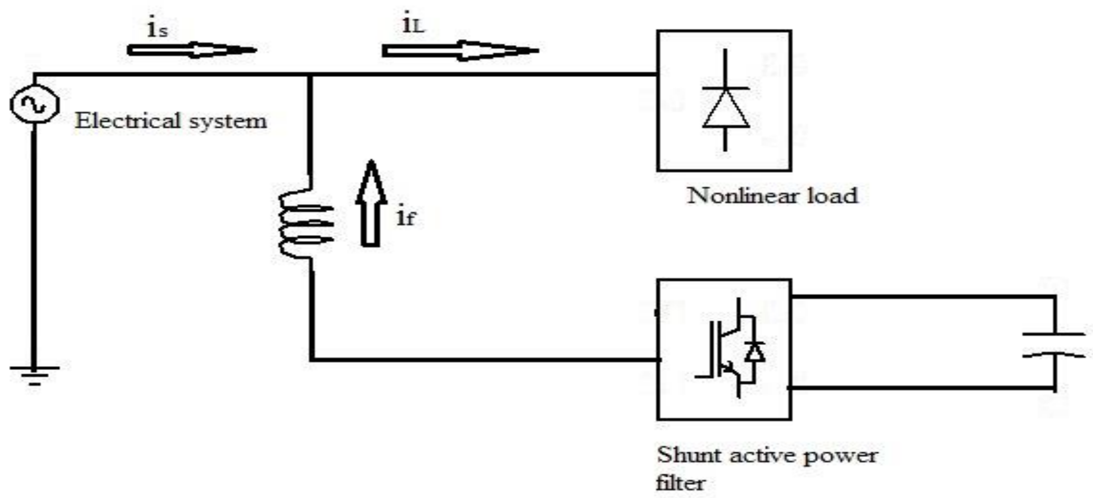

Fig.3.5. Schematic diagram of a shunt active filter.

Fig.3.5 shows a 1-phase or 3-phase diode rectifier with a capacitive dc load which can filter current harmonics. This is a very fundamental system design which can be modified further. The dc load can be treated as ac motor driven by a voltage source PWM (VS-PWM) inverter. This active filter has been connected in parallel with the harmonic generating load. “Feed forward” method has been implemented to control the filter.

- The instantaneous load current is observed by the controller.
- From the detected load current harmonic current is pulled out with the help of DSP.

- To cancel out the harmonic current, active power filter draws compensating current from utility supply.

Series active filter circuit configuration:-

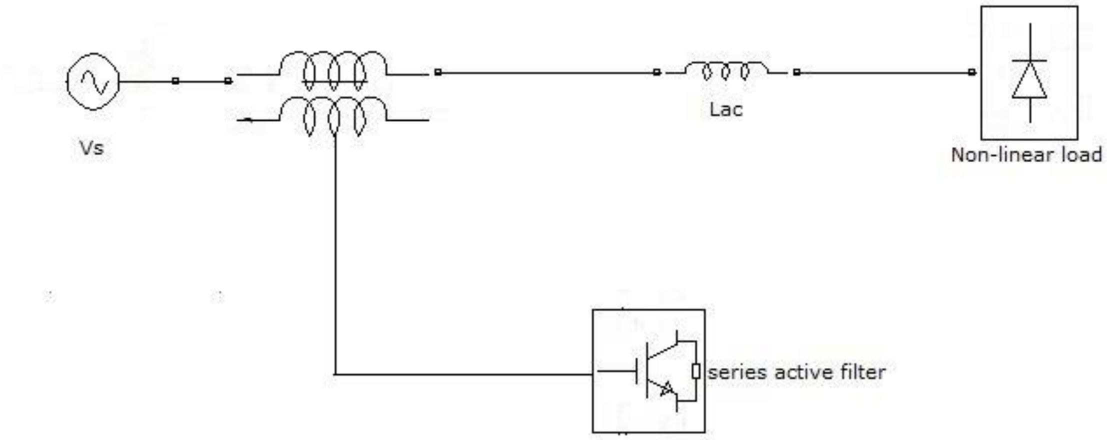

Fig.3.6. Schematic diagram of series active filter.

Fig.3.6 works for voltage harmonic filtering in case of 1-phase and 3-phase diode rectifier with a capacitive dc load. The series active filter is series connected with the power supply. This filter controls on the basis of "Feedback" manner.

- Instantaneous supply current is detected by controller.
- Harmonic currents are extracted from the supply current by means of DSP.
- The active filter applies the compensating voltage across the primary of transformer. This reduces the supply harmonics significantly.[9]

3.1.3. HYBRID FILTERS:

Hybrid filters are based on the combination of active filters and passive filters. Such a combination with the passive filter makes it possible to significantly reduce the rating of the active filter. The task of the active filter is not to compensate for harmonic currents produced by the thyristor rectifier, but to achieve “harmonic isolation” between the supply and the load As a result, no harmonic resonance occurs, and no harmonic current flows in the supply.

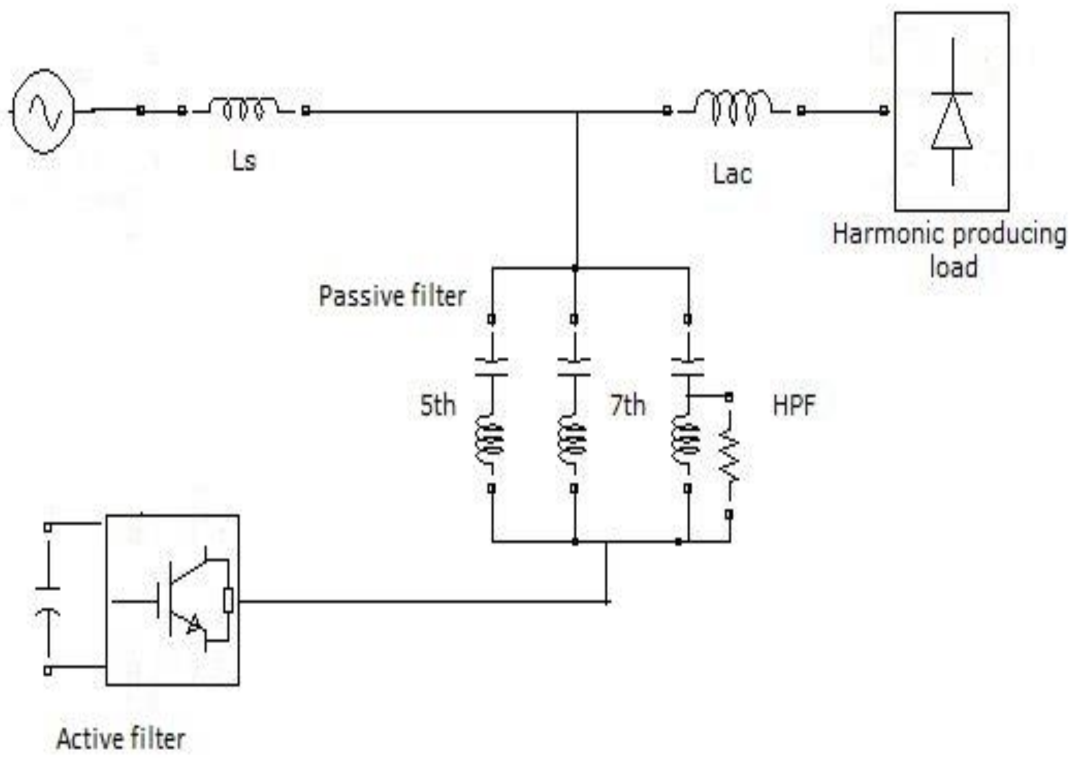

Fig.3.7. Series connection of an active filter and a passive filter.

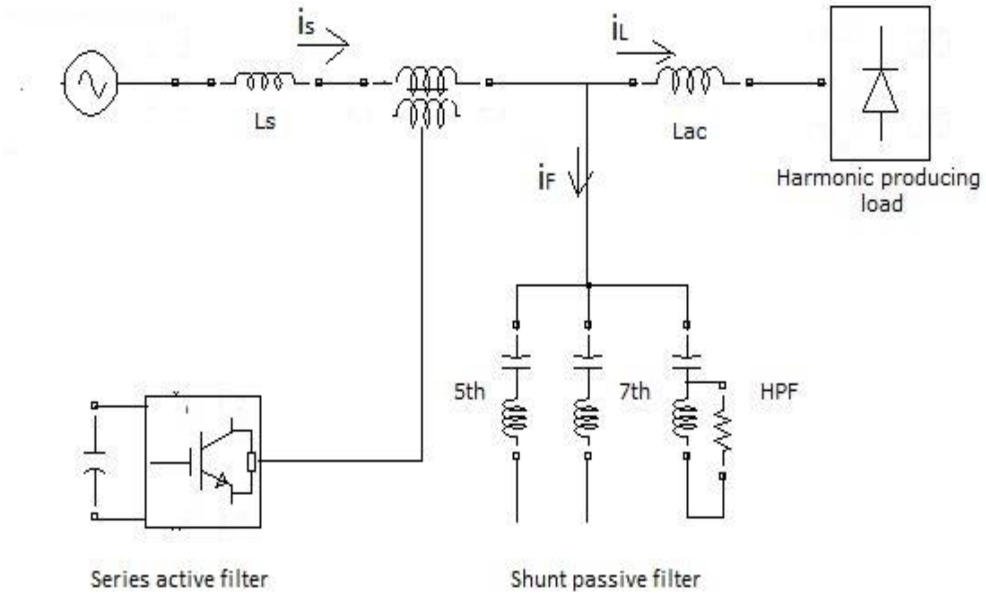

Fig. 3.8. Combination of series active filter and shunt passive filter.

The hybrid filters shown in fig.3.7 and fig.3.8 provide viable and effective solutions to harmonic filtering of high-power rectifiers. However, they have difficulty in finding a good market because of the necessity of the transformer and the complexity of the passive filter.

3.2. TOPOLOGY OF SINGLE PHASE SHUNT ACTIVE POWER FILTER:

The SPSAPF shown in fig.3.9 consists of a single-phase full-bridge voltage–source PWM inverter, a DC bus capacitor C_{DC} and an inductor L_C. The inductance, through which the inverter is connected to the power supply network, ensures, firstly, the controllability of the active filter current and acts, secondly, as a first-order passive filter attenuating, thus, the high frequency ripples generated by the inverter. The filter operates as current source, which cancels the current-type harmonics and exchanges the necessary reactive energy required by the non-linear load. A single-phase diode bridge rectifier feeding a series R-L circuit is chosen to represent the non-linear load.

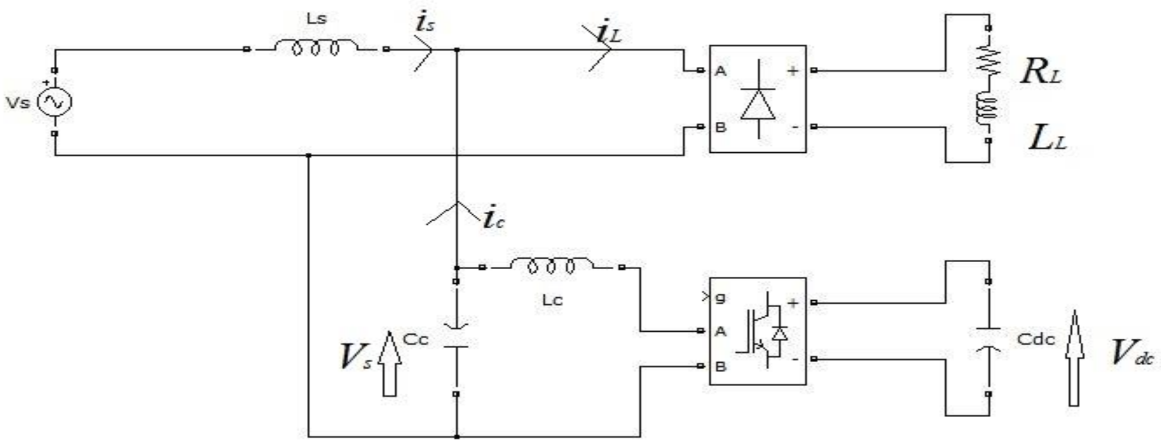

Fig. 3.9. Single phase shunt active power filter.

3.3. SINGLE PHASE SHUNT HYBRID POWER FILTER TOPOLOGY:

The SPSHPF shown in fig.3.10 consists of a full-bridge voltage–source PWM inverter, a DC side capacitor C_{DC}, an inductor L_C, a transformer and a power factor correction (PFC) capacitor C_C. The primary winding of the transformer is fed by the inverter. The PFC capacitor and the secondary winding of the transformer are connected in series to form a branch parallel to the non-linear load. The iron core of the transformer contains an air-gap in order to reduce its magnetizing inductance L_μ. The PFC capacitor C_C and the magnetizing inductance L_μ create a second-order filter tuned at the third harmonic.

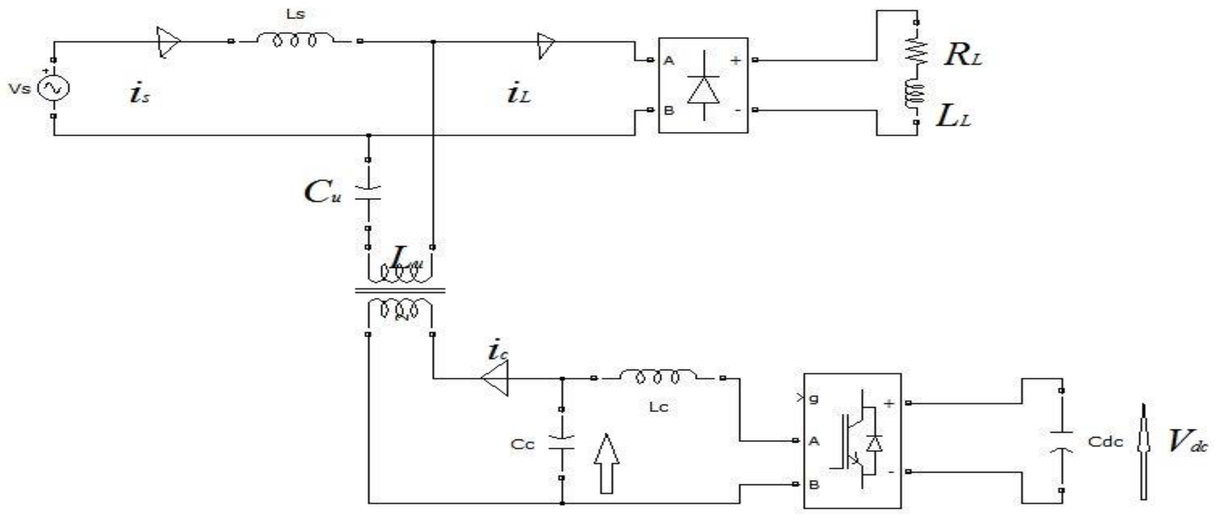

Fig. 3.10. Single phase hybrid power filter.

3.4. SERIES CONNECTION OF PASSIVE AND ACTIVE FILTER TOPOLOGY:

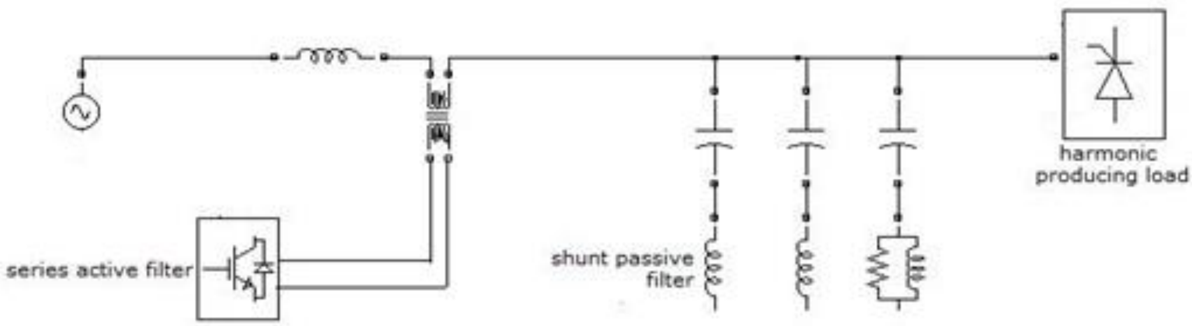

Fig.3.11. Combination of a series active filter and a shunt passive filter.

In fig.3.11 the shunt passive filter connected in parallel with a load suppresses the harmonic currents produced by the load, while the active filter connected in series to a source acts as a “harmonic isolator” between the source and the load. Hence a hybrid filter helps to overcome the drawbacks of passive filter and active filter used alone. [12]

CHAPTER 4

Methodology

4.1. EXTRACTION OF REFERENCE CURRENT

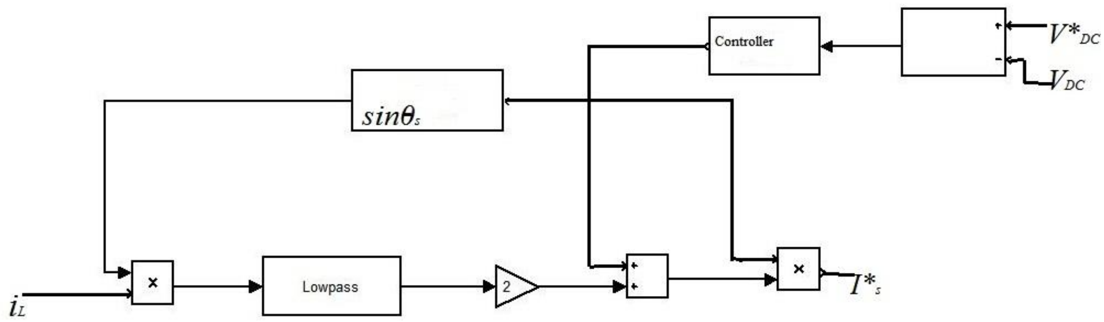

Fig.4.1. Indirect current control algorithm of SPSAPF system.

The method employed for drawing out the reference current in a filter affects the execution of it to a great extent. Direct current control and indirect current control are the two methods for extraction of the source current reference. The difference between the expected current i_c^* and the real current i_c at the AC input of the filter gives the error for direct current control scheme. The deviation of the sensed source current i_s from the reference source current i_s^* forms the error for the indirect current control method. Considering indirect current control as shown in fig.4.1 the current reference extraction method is based on the determination of the amplitude of the fundamental active current I_{Lf}, which is achieved by the use of classic demodulation technique. The current of the non-linear load i_L is expressed by:

$$i_L(\theta_s) = \sum_{n=1}^{\infty} I_{Ln} \sin(n\theta_s - \varphi_n) = I_{L1} \sin(\theta_s - \varphi_1) + \sum_{n=2}^{\infty} I_{Ln} \sin(n\theta_s - \varphi_n) \quad (4.1)$$

Here φ_1 shows phase angle of fundamental load current, $\theta_s = \omega t$, I_{L1} the magnitude of the fundamental current, $I_{Ln}$the magnitude of the nth harmonic load current, and φ_n the angle of the *n*th harmonic load current.

The fundamental component i_{Lf} and the harmonic components $i_{Ln}$of the load current i_L, are given by:

$$i_{Lf} = I_{L1} \sin(\theta_s - \varphi_1) \quad (4.2)$$

$$i_{Ln} = \sum_{n=2}^{\infty} I_{Ln} \sin(n\theta_s - \varphi_n) \quad (4.3)$$

The fundamental current can be separated to two parts:

Fundamental active current, $i_{Lfa} = I_{L1} \cos\varphi_1 \sin\theta_s$ (4.4)

Fundamental reactive current, $i_{Lfr} = I_{L1} \sin\varphi_1 \cos\theta_s$ (4.5)

This method can eliminate both active and reactive components simultaneously. The objective is to cancel the harmonics and to compensate the reactive power. Hence, the reference current for the active filter i_s^* is equal to the fundamental active current i_{Lfa}:

$$i_s^* = i_{Lfa} = i_L - (i_{Ln} + i_{Lfr}) \quad (4.6)$$

In order to simplify the filtering of the load current i_{Ln}, the fundamental component i_{Lfa} is transformed into the DC component. Multiplying both sides of by $\sin\theta_s$,

$$i_L(\theta_s)\sin\theta_s = \frac{I_{L1}}{2}\cos\varphi_1 - \frac{I_{L1}}{2}\cos(2\theta_s - \varphi_1) + \sin\theta_s \sum_{n=2}^{\infty} I_{Ln}\sin(n\theta_s - \varphi_n) \quad (4.7)$$

Above equation shows the presence of a DC component and the AC components of which minimal frequency is equal to twice the frequency network (100 Hz). A low pass filter, with a relatively low cut-off frequency is used to prevent the high frequency component entering the output. However, it is indispensable to respect a good compromise between the effective filtering of frequencies parasites and the fast dynamics of the extraction algorithm. The filtered output current is therefore given by:

$$(i_L \sin\theta_s)_{filtered} = i_{Lf} = \frac{I_{L1}}{2}\cos\varphi_1 \quad (4.8)$$

The error between the reference value V_{dc}^{*} and the sensed feedback value V_{dc} is processed towards a PI controller giving I_{cm} signal. This current is added to $2i_{Lf}$, leading the peak value of the reference current. In order to reconstitute the fundamental active reference current,

peak value is multiplied by $\sin\theta_s$. The block diagram of the proposed control algorithm of the active filter with indirect current control is shown in the above figure.[10]

4.2. GENERATION OF THE GATE SIGNAL WITH THE U-PWM

As shown in fig.4.2 the current reference i_s^* (obtained from the extracting algorithm described above) is compared with the sensed current i_s. The error signal is fed to the current controller having a limiter at its output. The regulation signal delivered by the controller and its opposite are then compared simultaneously with a triangular carrier resulting in the switches gate signals.

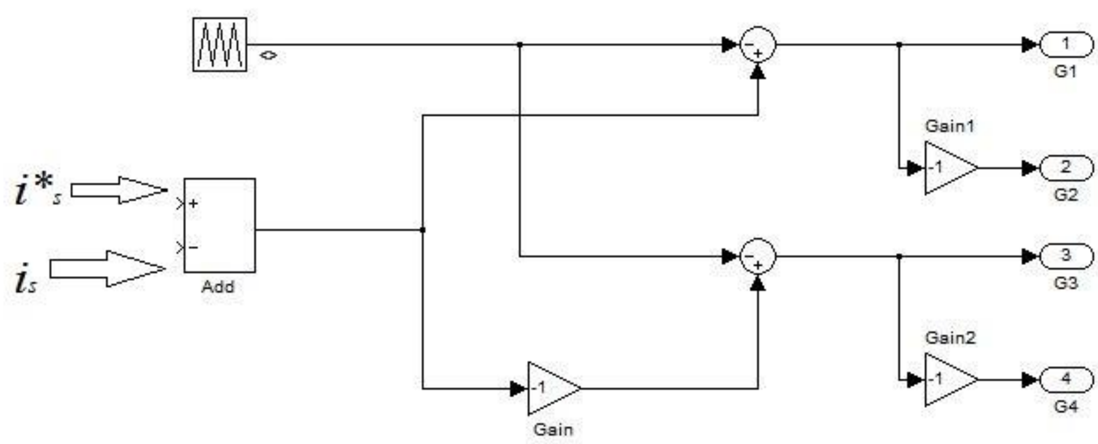

Fig.4.2. Gating signals generation using the unipolar PWM.

We have used the various methods for single phase filters. Now we'll discuss the method for series connected active and passive filter for three-phase system.

4.3. SYSTEM CONFIGURATION AND CONTROL CIRCUIT FOR SERIES CONNECTION OF ACTIVE FILTER AND PASSIVE FILTERS:

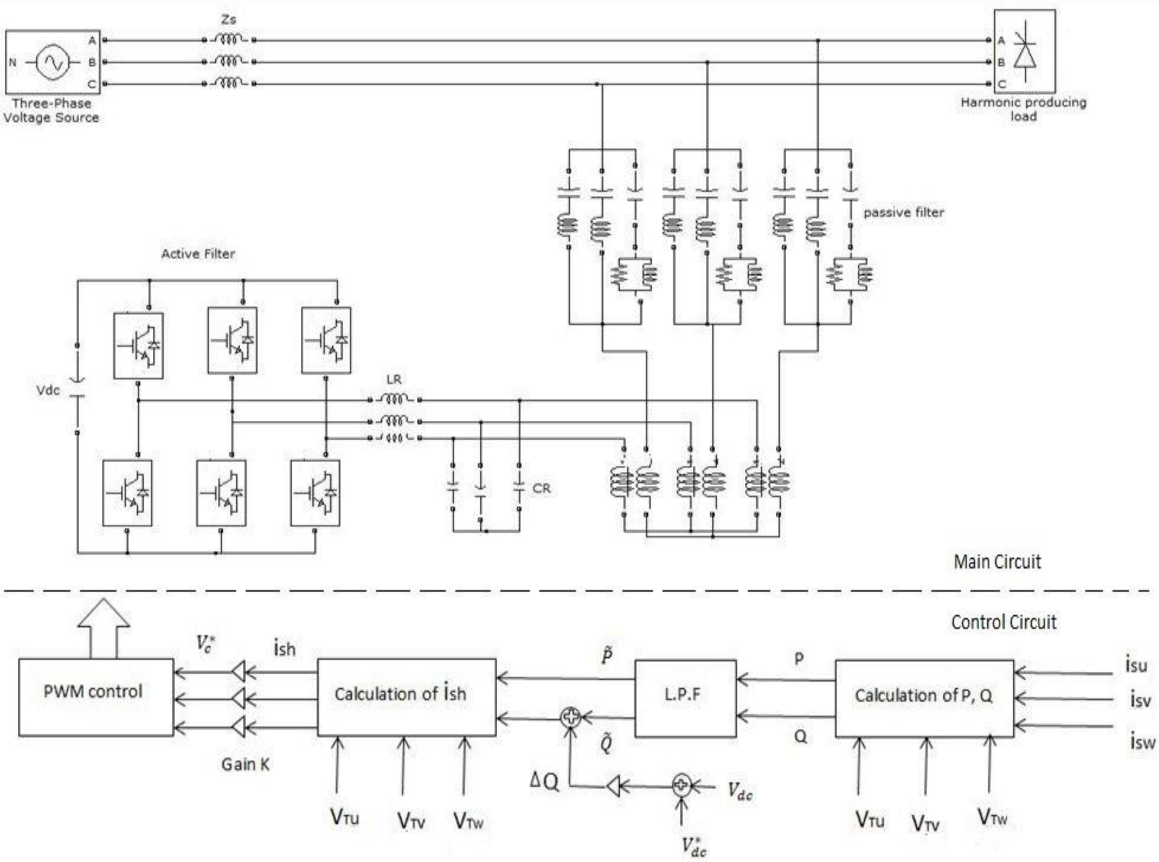

Fig.4.3. System configuration.

A control circuit is shown in fig.4.3. Three-phase source currents $i_{su},\ i_{sv}, i_{sw}$ are detected. A source harmonic current in each phase i_{sh} is calculated by applying the p-q theory. Following equations show how the terminal voltages and source currents are changed from three phase to two phase quantities:

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} \begin{bmatrix} e_u \\ e_v \\ e_w \end{bmatrix} \tag{4.9}$$

$$\begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} \begin{bmatrix} i_{Su} \\ i_{Sv} \\ i_{Sw} \end{bmatrix} \tag{4.10}$$

Here e_u, e_v, e_w are the fundamentals of the terminal voltages. Hence, the instantaneous real power p and the instantaneous imaginary power q are given by

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} \tag{4.11}$$

In the above equation, the fundamental of i_s is transformed to dc components $\tilde{p}$, $\tilde{q}$ and the harmonics to ac components $\tilde{p}$ and $\tilde{q}$**.** Two high pass filters are used to take out the ac components. The harmonics of the source currents $i_{Shv}, i_{Shu}, i_{Shw}$ are found employing the following equation:

$$\begin{bmatrix} i_{Su} \\ i_{Sv} \\ i_{Sw} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -0.5 & 0.866 \\ -0.5 & -0.866 \end{bmatrix} \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \tag{4.12}$$

The gain K is multiplied with harmonic currents of each phase i_{sh}. The resulting voltage is input to the PWM which is:

$$v_C^* = K \, . \, i_{Sh} \tag{4.13}$$

In the PWM controller the voltage v_c^* is compared with a triangular carrier wave to produce the gating signals. The frequency of the triangular wave is of the order of 20 kHz. The dc capacitor voltage can be governed by the active filter. The phase alignment of fundamental component of the active filter output voltage with the fundamental leading current of the passive filter can give rise to active power formed by them. This active power is supplied to the dc capacitor.[11]

CHAPTER **5**

Results

5.1. SIMULATION RESULTS WITH THE SHUNT ACTIVE POWER FILTER

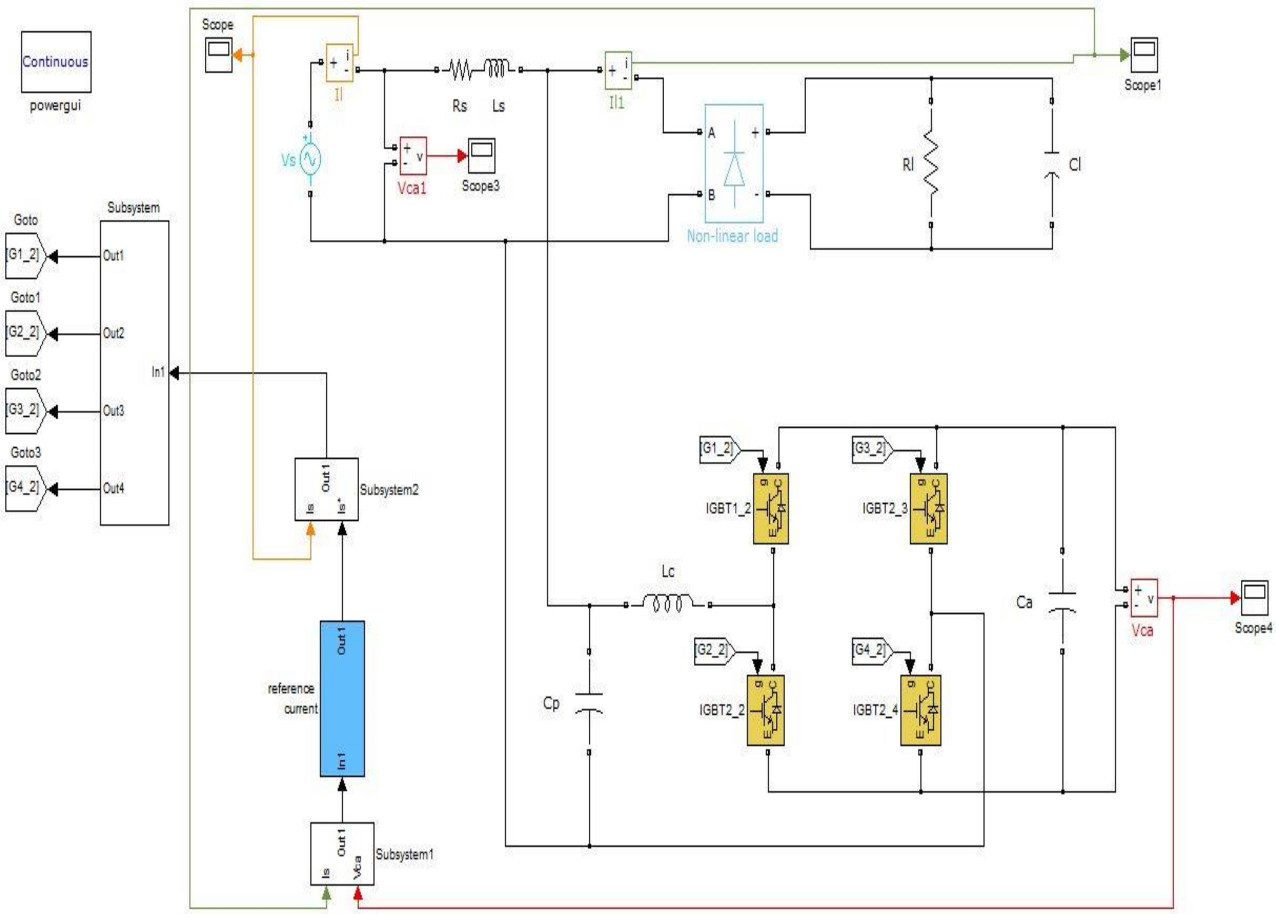

Fig.5.1. Simulink model of Active power filter.

Fig.5.1 shows a simulink model of active power filter. The DC-link voltage V_{ca} is set to 350V and its capacitance has a value of C_{dc}= 2000 μF. The converter output inductance L_c, used to smooth the filter output current i_c, equals 1 mH. The average switching frequency of the insulated gate bipolar transistors (IGBTs) is approximately 8 kHz.

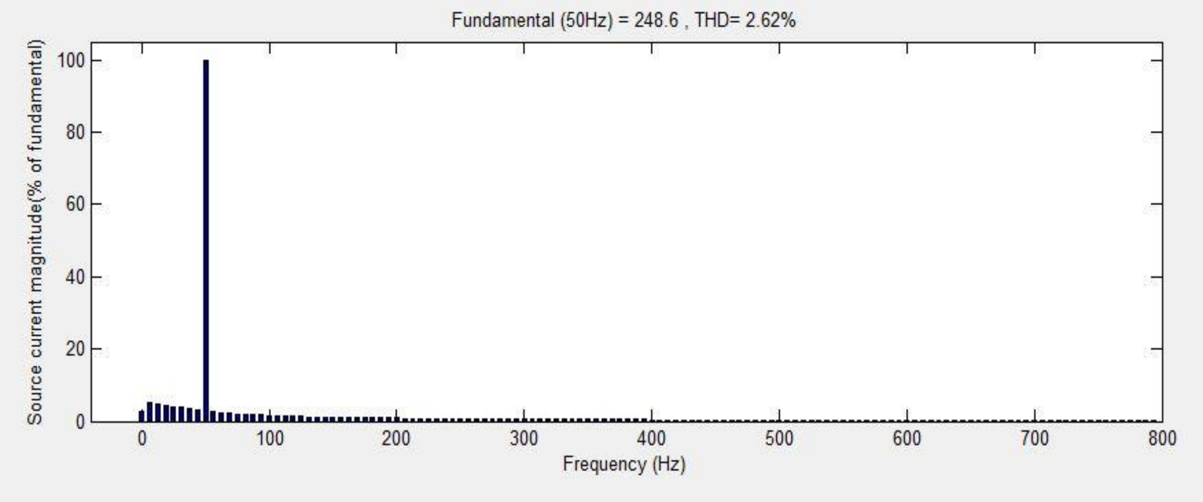

Fig.5.2. Source currents THD in case of shunt active power filter.

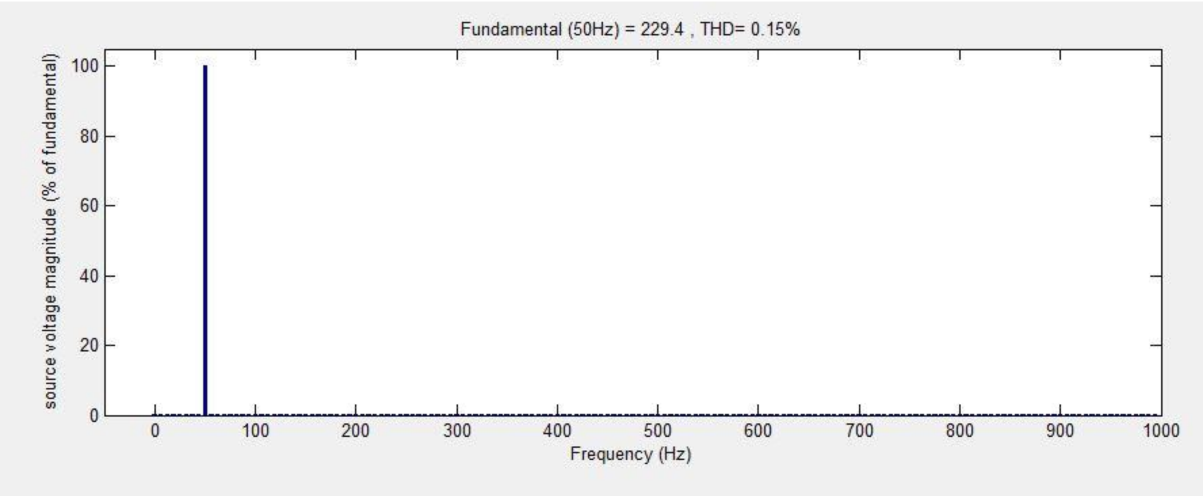

Fig.5.3. Source voltages THD in case of shunt active power filter.

In case of a shunt active power filter source current has a THD of 2.62% and source voltage has a THD of 0.15%. This shows the effect of shunt active power filter and the THD comes below 5%. This is clear from fig.5.2 and fig.5.3.

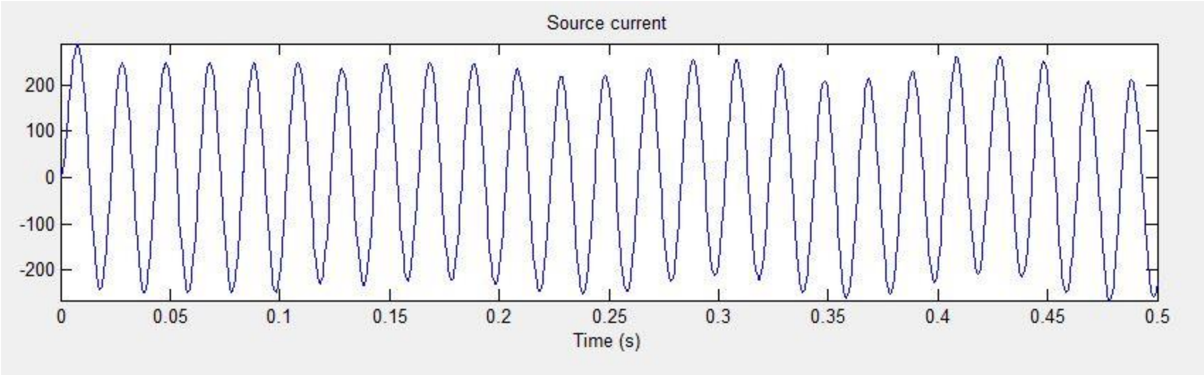

Fig.5.4. Source current waveforms in case of active power filter.

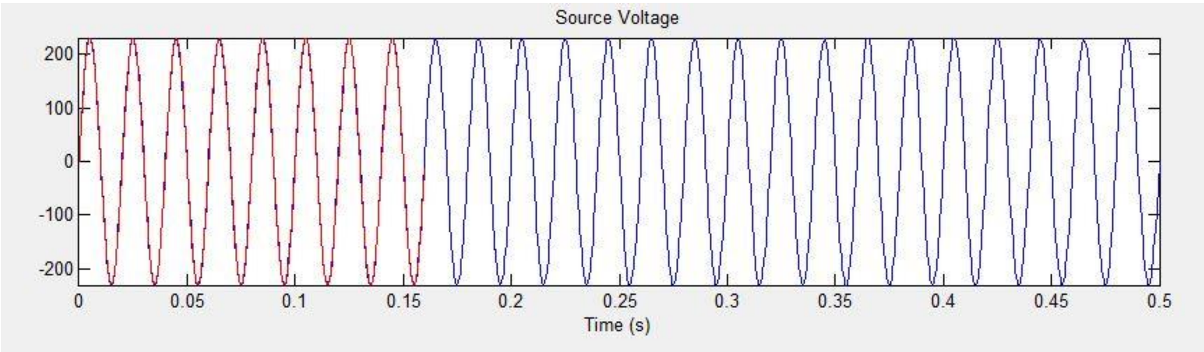

Fig.5.5. Source voltage waveforms in case of active power filter.

Fig.5.4 shows the source current waveform in case of an active power filter. The fundamental component of the source current has amplitude of 248.6 amperes. Fig.5.5 shows the waveform of source voltage in case of an active power filter. The fundamental component of the source voltage has amplitude of 229.4 volts.

5.2. SIMULATION RESULTS WITH THE SHUNT HYBRID POWER FILTER

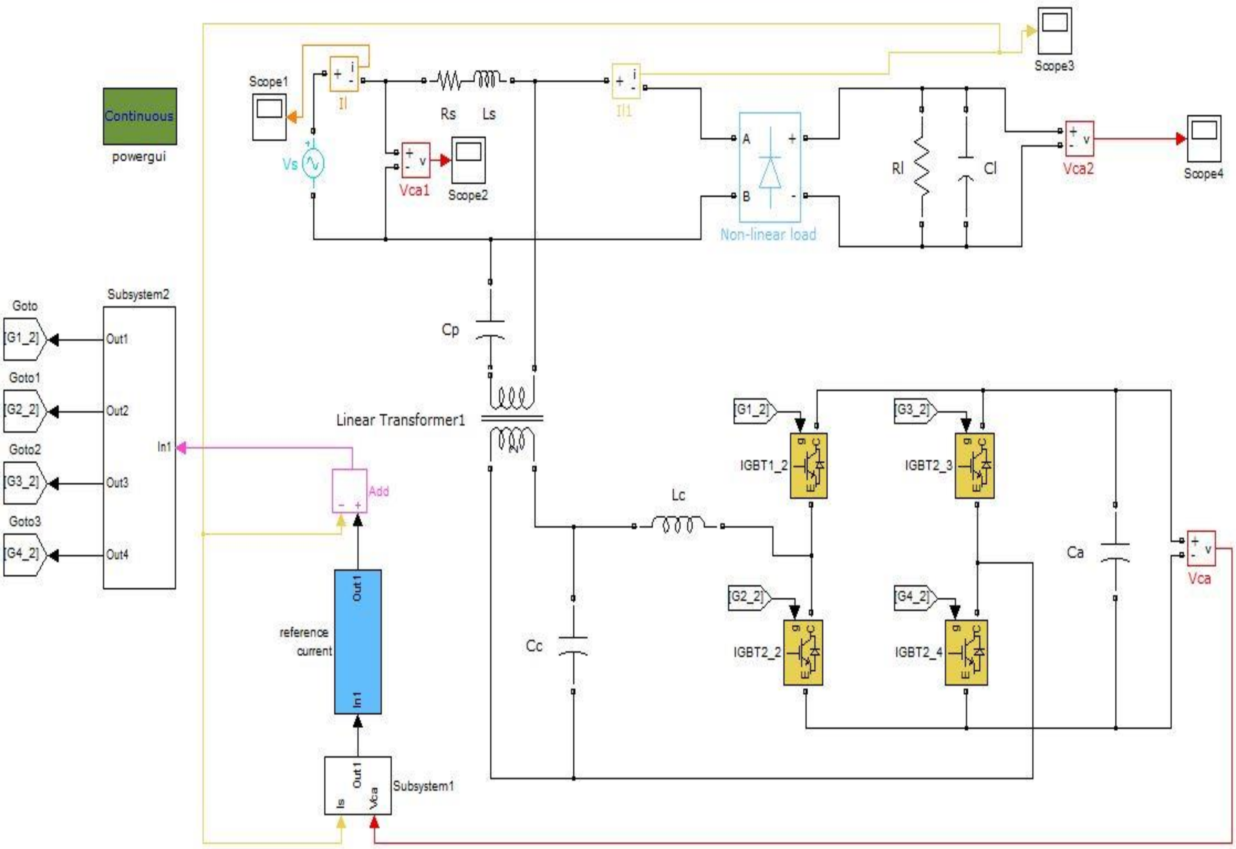

Fig.5.6. Simulink model of the hybrid power filter.

Fig.5.6 shows a simulink model of hybrid power filter. The DC-link voltage $V_{ca}$is set to 350V and its capacitance has a value of C_{dc}= 2000 μF. The converter output inductance L_c, used to smooth the filter output current i_c, equals $1\, mH$. The average switching frequency of the insulated gate bipolar transistors (IGBTs) is approximately 8 kHz.

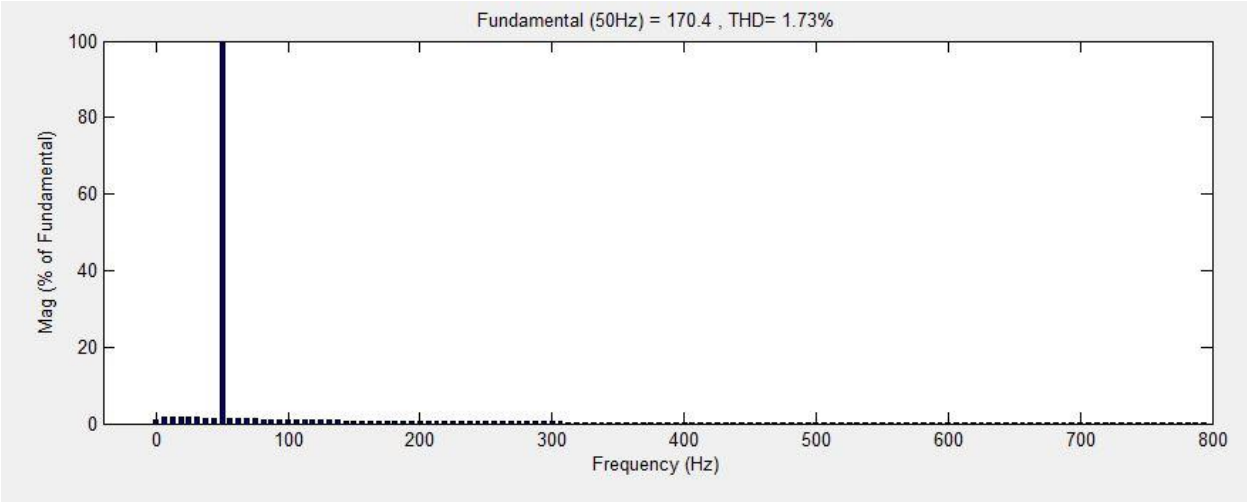

Fig.5.7. Source currents THD with Hybrid power filter.

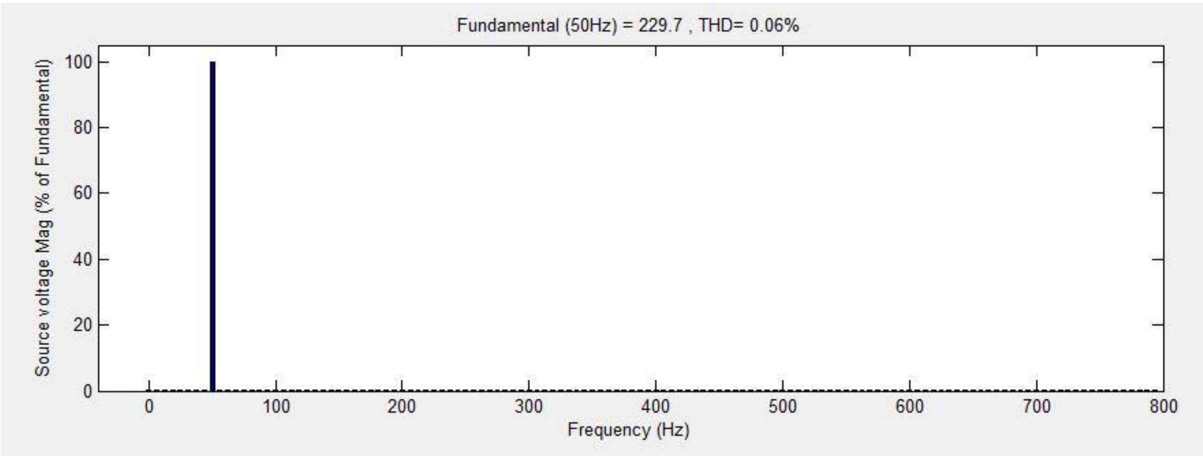

Fig.5.8. Source voltages THD with Hybrid power filter.

In case of a shunt hybrid power filter source current has a THD of 1.73% and source voltage has a THD of 0.06%. This shows the effect of shunt hybrid power filter and the THD comes below 5%. This is clear from fig.5.7 and fig.5.8.

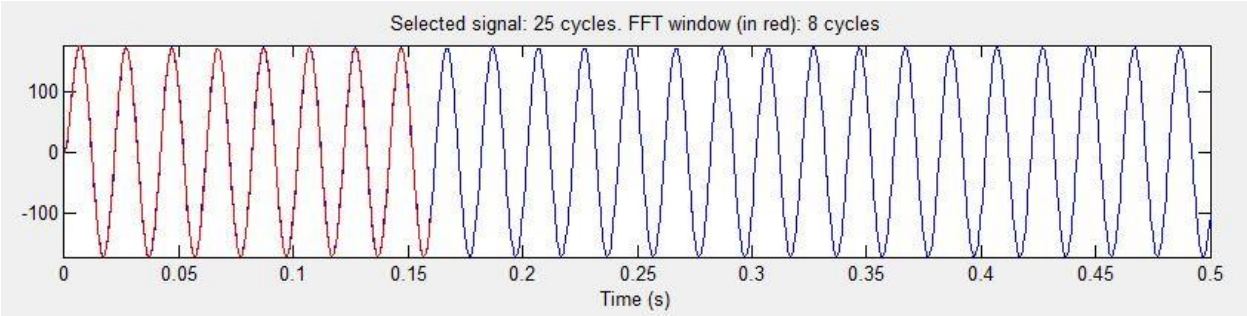

Fig.5.9. Source current in case of Hybrid filter.

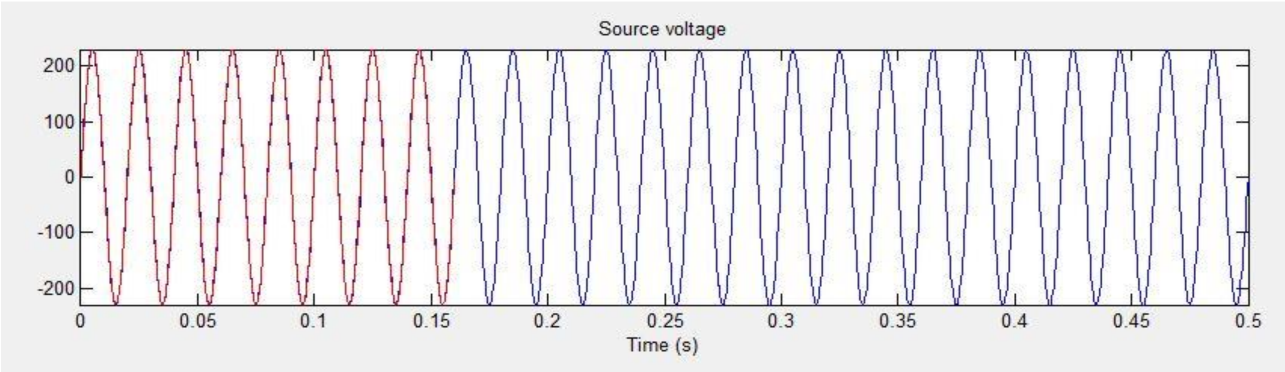

Fig.5.10. Source voltages in case of Hybrid filter.

Fig.5.9 shows the source current waveform for hybrid power filter. The amplitude of fundamental component is 170.4 amperes. After the implementation of the hybrid filter the THD is reduced to 1.73%. This indicates a great performance. Also the waveform is almost sinusoidal. Fig.5.10 shows the source voltage waveform for the case of hybrid filter. It is almost sinusoidal having amplitude of fundamental of 229.7 volts.

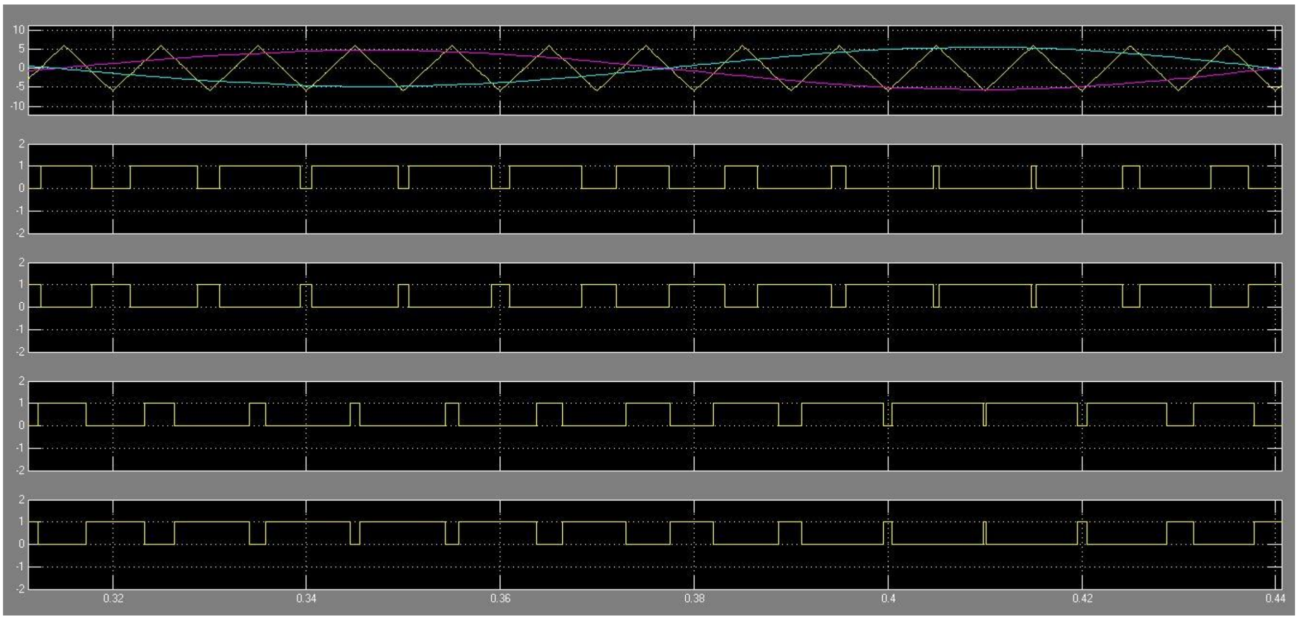

Fig.5.11. PWM gating signals generation using U-PWM technique.

The gating signal generation method is based on the comparison between slowly varying regulating signals with a high frequency carrier signal. This has been shown in fig.5.11. The first two gate signals are obtained from the positive regulating signal, while the other two gating signals are obtained from the negative regulating signal.

5.3. SIMULATION RESULTS WITH THE SERIES CONNECTED ACTIVE AND PASSIVE FILTER:

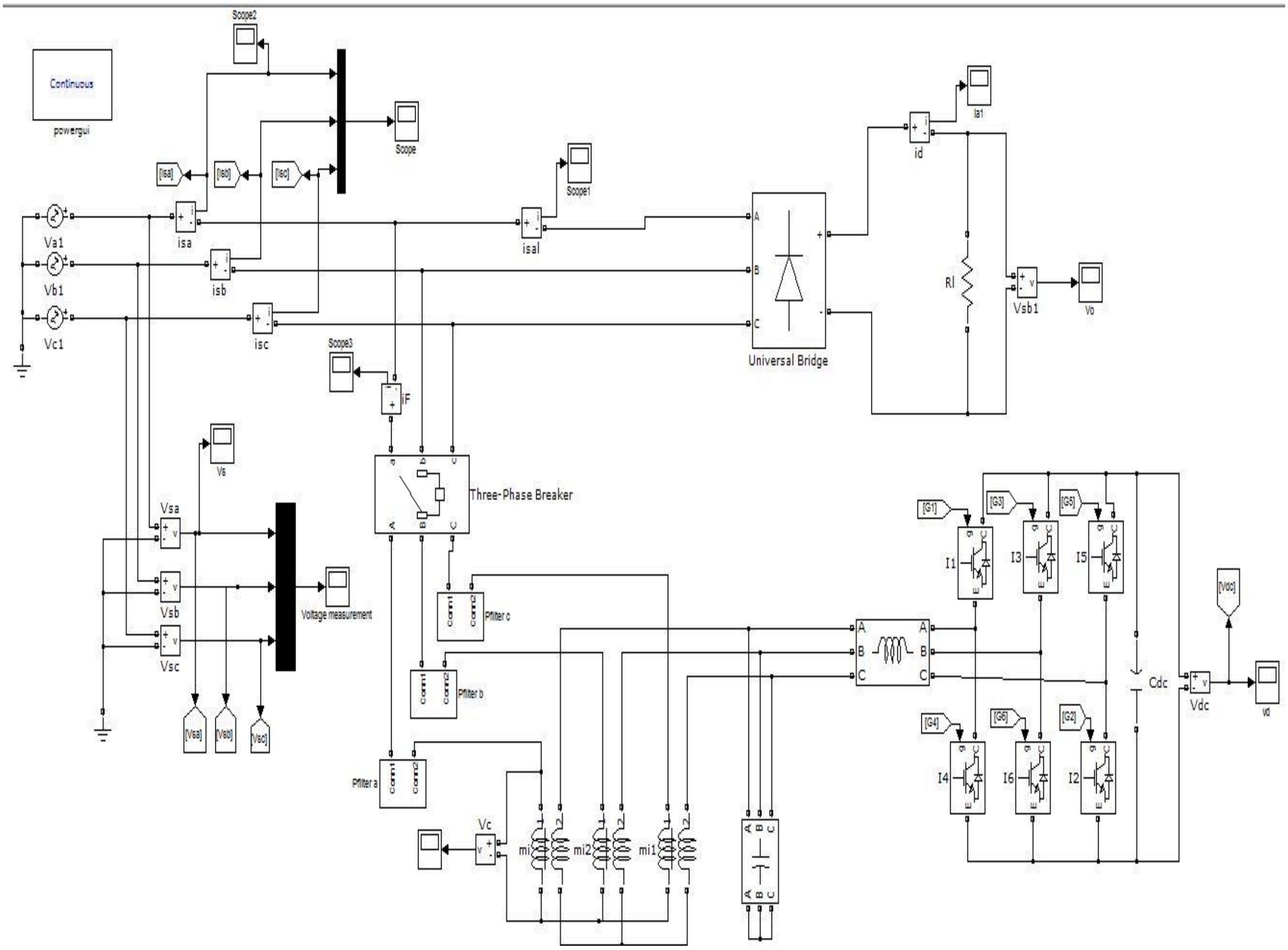

Fig.5.12. Simulink diagram for series connected active and passive filter.

The fig.5.12 shows the Simulink model for series connected active and passive filter. Here we have a three phase source. The load is consisting of a diode bridge rectifier with a resistive path connected in the dc side. From the line the filter is connected via a breaker. The switching of filter is done after 0.15 sec. The passive filter connected is shown in the block diagrams named as filter a, filter b, filter c and various waveforms are observed.

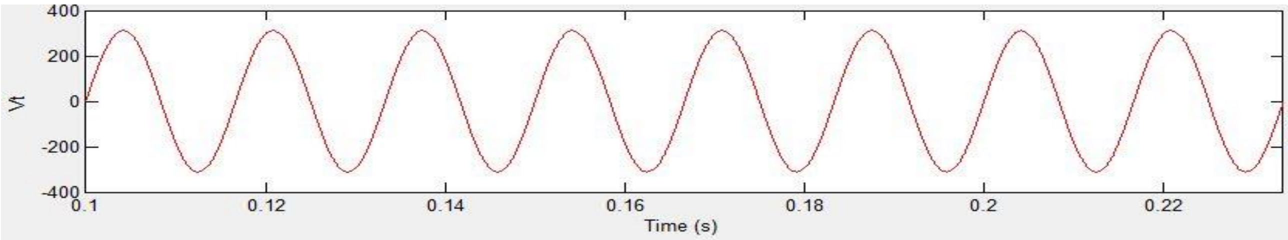

Fig.5.13. Terminal voltage waveforms.

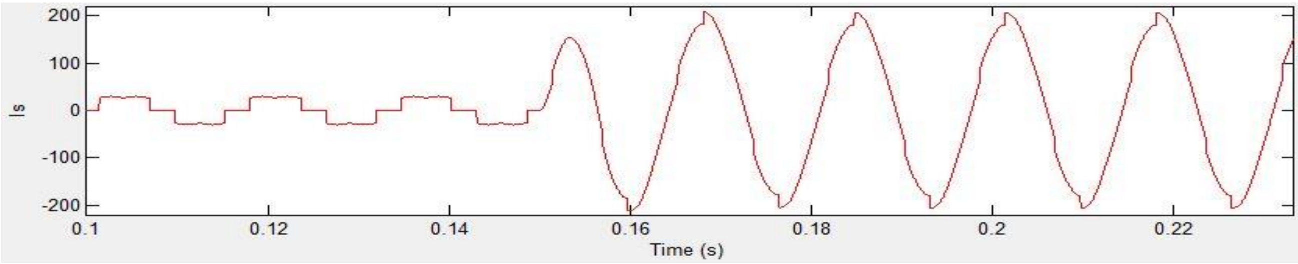

Fig.5.14. Source current waveforms.

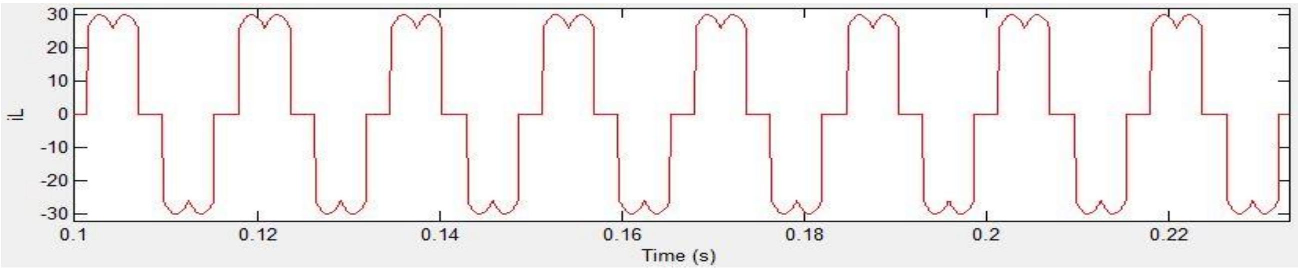

Fig.5.15. Load current waveforms.

Terminal voltage or the source voltage waveform is sinusoidal one as in fig.5.13. The fundamental of source voltage waveform has amplitude of 310.9 volts.Fig.5.14 shows the source current waveform. The current is distorted before the switching of the filter and has amplitude of 30 amperes. After the switching on of the filter the source current waveform becomes almost sinusoidal. The fundamental component has amplitude of 196.6 amperes.Fig.5.15 shows the load current waveform. Due to the presence of highly non-linear load the current is contaminated with harmonics and the waveform is distorted one. It has amplitude of 30 amperes.

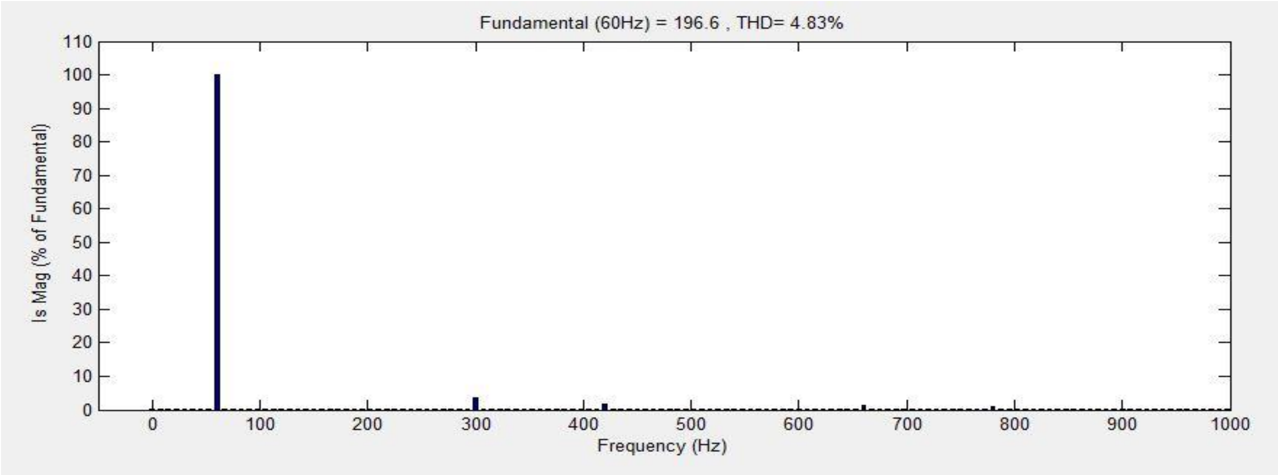

Fig. 5.16. Source current THD.

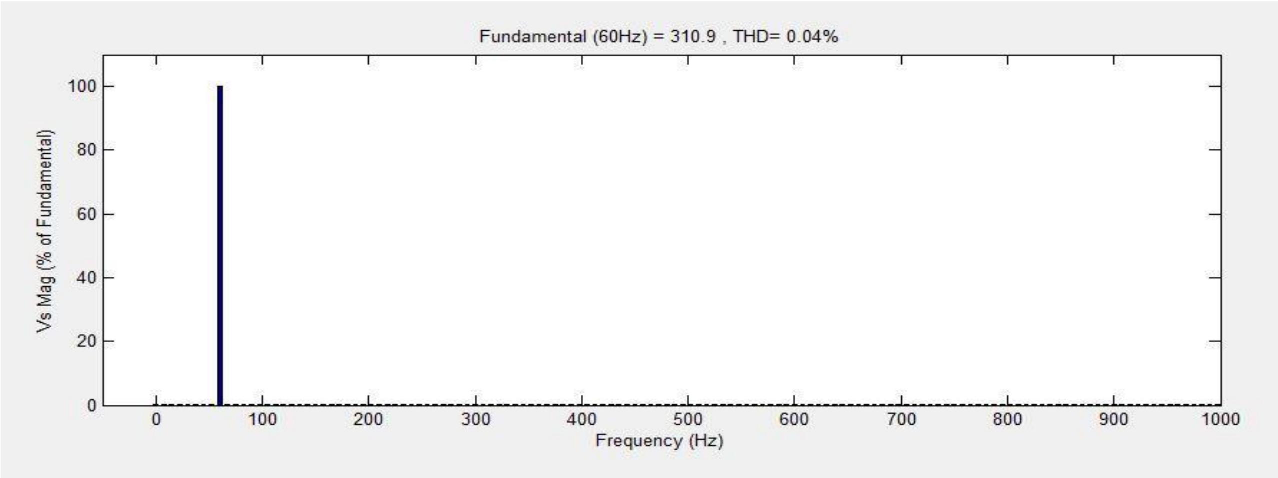

Fig. 5.17. Source voltage THD.

The source voltage has a THD of 0.04%. The source current has a total harmonic distortion of 4.83%.

5.4. TABLE:

Quantity	THD (%) before compensation	THD (%) after compensation	
	Without filter	With hybrid filter	With active filter
Supply current	23.24	1.73	2.62
Supply voltage	1.3	0.06	0.15
		Three phase hybrid filter	
Supply current	30.63	4.83	
Supply voltage	0.54	0.04	

The table shows the behaviour of the system under various filter configurations. For the single phase system the source current has a THD of 23.24% before implementing the filter. With the compensation by the active power filter we are achieving a THD of 2.62%. But after implementing a hybrid filter in the place of active filter we are getting a THD of 1.73%. This shows a great reduction in the harmonics. Also voltage harmonics are very less after implementing the filters. Similarly for the three phase case before connection of the filter across the line we are getting a source current THD of 30.63% and a source voltage THD of 0.54%. Due to the implementation of the series connected active filter and passive filter source current THD is getting reduced to 4.83% and source voltage THD to 0.04%.

CHAPTER **6**

Conclusion & Future Work

CONCLUSION:

This project report describes a comparative study between single-phase shunt active power filter (SPSAPF) and a single-phase shunt hybrid power filter (SPSHPF). Simulation results proved that performance of the SPSHPF is much better than the SPSAPF. The DC-link voltage of SPSAPF is twice more than that of SPSHPF. SPSHPF has a filter current which is reduced by factor 2 also switching frequency reduced by a factor 3 compared to SPSAPF. The application of UPWM to generate gating signals has advantages such as elimination of group of harmonics that centred on odd multiples of switching frequency.

The combined system of passive and an active filter has following features-

1. Source impedance no longer governs the filtering characteristics.

2. The active filter has the ability to dump the parallel and series resonance between the source and the passive filter.

3. In this case the required rating of active filter is much less than a conventional active filter used alone. This happens due to passive filters having high quality factor, as the rating of active filter connected in series will come down in inverse proportion of quality factor of passive filter.

FUTURE WORK:

Experimental investigations can be done on shunt active and hybrid power filter, series connected passive and active filter by developing a prototype model in the laboratory to verify the simulation results for both P-I and hysteresis controllers.

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APPENDIX

Supply voltage	230 V	Source resistance	0.25 ohm
Supply frequency	50 Hz	Source inductance	2.5 mH
Dc bus reference voltage	300 V	Load resistance	0.25 ohm
Dc bus capacitance	2000 μF	Load capacitance	500 μF